ThA4
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Micromachined Polarization Beam Splitters for the Visible Spectrum

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We have built and characterized batch-processed polarization beam splitters (PBS), important optical components to separate the orthogonal TE and TM components of light. The devices were fabricated from thin-film, low-stress silicon nitride membranes and showed excellent performance. By stacking membranes, and a triple-layer PBS produced extinction ratios of 21 and 16dB for reflected and transmitted light rays, respectively.

In order to obtain the optimal performance for a thin-film PBS, the film thickness must be accurately controlled. For 635-nm light and a thin-film membrane of silicon nitride (refractive index = 2.1), the thickness should be an integral multiple of 83.5 nm [2]. In order to obtain reasonable yield in our processing, we aimed for a desired thickness of 417.5nm (five times the minimum thickness) trading off transmission through the film with membrane strength. A disadvantage of a thin-film PBS is that it shows a low extinction ratio for the transmitted TM mode since transmitted light still contains some TE mode. This disadvantage can be alleviated by employing multi-layer thin-film PBS to filter out more of the remaining TE mode in the transmitted light.

The fabrication steps are shown in Figure 1. Using low-pressure chemical-vapor deposition (LPCVD), we deposited a low-stress silicon nitride layer on *p*-type silicon wafers, aiming for a thickness slightly greater than the target value. Then, we reduced the nitride thickness down to the target value in a 160°C, phosphoric acid bath (Figure 1a). Next, we created etch windows by photolithographic-patterning and dry-etching the nitride layer on the backside of the wafers (Figure 1b) [3]. To open the window cavity (4.25mm square), we used 80°C KOH to etch through 530-μm (+/-5 μm) Si, leaving only the nitride membrane over the cavity (Figure 1c). Measurements using NANO Deep-UV System showed that the final thickness of the membranes varied from 418.8 to 419.5 nm. Using a WYKO NT3300, we measured the radius-of-curvature of a typical nitride membrane to be 51 m; the membranes are virtually flat! Figure 2 shows several of the fabricated membranes: single-, double-, and triple-layer nitride membrane PBS. For a multi-layered PBS, membranes are stacked at an angle to clear the optical path for transmitted light.

Figure 3 indicates a possible design to integrate our thin-film PBS into an optical-MEMS by employing silicon nitride windows in pop-up structures. Such a system could be fabricated in an SOI process.

To calibrate our silicon nitride membrane PBS, a 635-nm beam from a laser diode was directed at the surfaces of both single- and stacked-PBS devices at the film Brewster angle (64.5°). The transmitted and reflected rays from the test structures were then passed through two Tech Spec™ 15mm High-Efficiency Polarizing-Cube Beamsplitters (reflection efficiency > 99.5%, transmission efficiency > 95%) using the system shown in Figure 4. The intensities of both TE and TM components were then measured using a photo detector. The insertion losses and extinction ratios derived from these measurements are listed in Table 1. Very good performance is demonstrated by the new MEMS PBS structures: extinction ratios (for reflected and transmitted light) of (21dB, 10dB), (21dB, 14dB), and (21dB, 16dB) for single-, double-, and triple-layer systems, respectively with corresponding insertion losses of 3, 10, and 13% . The stacked PBS devices clearly exhibit the expected improvements over single-layer splitters in the transmitted extinction ratios.

A literature search led us to 1998 work by Pu, Zhu and Lo who investigated a MEMS-compatible surface-micromachined PBS made using thin-film polycrystalline silicon. They achieved extinction ratios of 21 and 10dB for reflected and transmitted light with an insertion loss of ~50%. For visible light, this polysilicon PBS is excessively lossy, and clearly not suitable for a stacked PBS.

References

[1] Pu, C., Zhu, Z., and Lo, Y.-H. 1998. Surface Micromachined Integrated Optic Polarization Beam Splitter. *IEEE Photonics Technology Letters*. 10: 7: 988–990.
[2] Born, M., and Wolf, E.1999. *Principles of Optics, Seventh Edition*. Cambridge, UK: Cambridge University Press.
[3] Ciarlo, D. R. 2002. Silicon Nitride Thin Windows for Biomedical Microdevices. *Biomedical Microdevices*. 4: 1: 63-68.

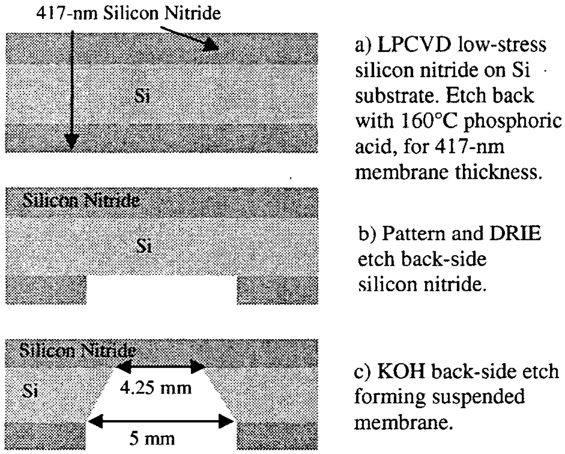

Figure 1 Beam splitter process flow

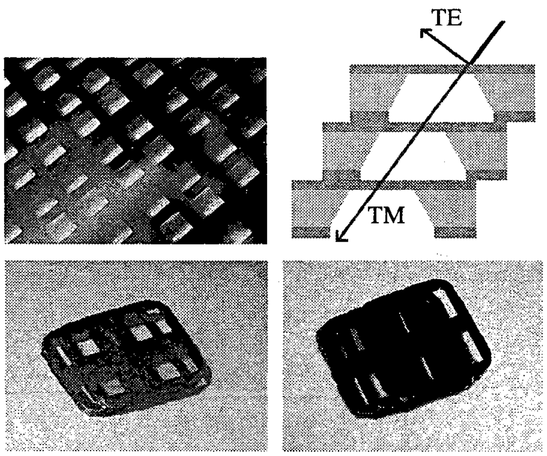

Figure 2 Single-, double-, triple-nitride membrane PBS

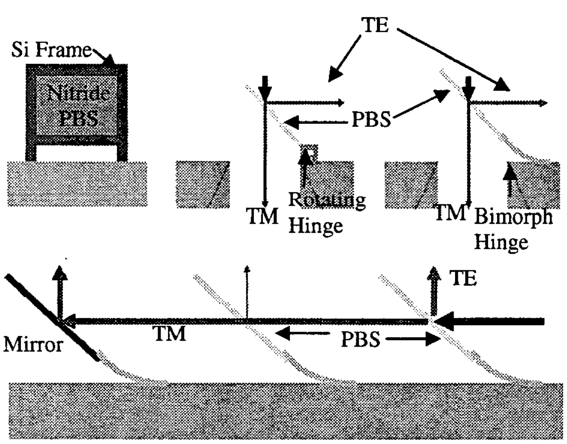

Figure 3 Possible integration schemes for the multi-layer PBS with MEMS structures

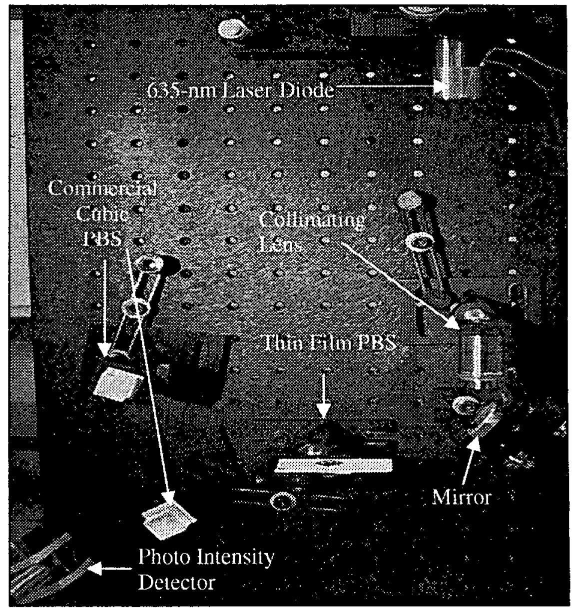

Figure 4 Optical testing setup

Table 1 Reflected and Transmitted Light Extinction Ratios for Nitride Membranes

	Single-Layer PBS*	**Double-Layer Stacked PBS**	**Triple-Layer Stacked PBS**
Insertion Loss	**3%**	**10%**	**13%**
$Reflected_{TE}$ $/Reflected_{TM}$	**99.2%**	**99.2%**	**99.2%**
$Transmitted_{TM}$ $/Transmitted_{TE}$	**90.9%**	**96.2%**	**97.5%**
Reflected Light Extinction Ratio (dB)	**21**	**21**	**21**
Transmitted Light Extinction Ratio (dB)	**10**	**14**	**16**
Film Thickness Layer 1 (nm)	419.3	419.5	419.5
Film Thickness Layer 2 (nm)	N/A	419.2	419.2
Film Thickness Layer 3 (nm)	N/A	N/A	419.5

* Average values for 10 different single-layer structures